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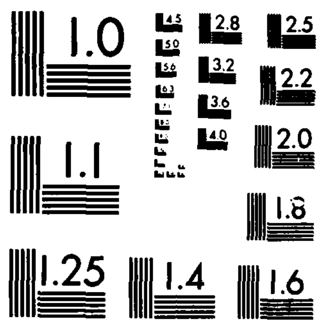

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NEARSHORE AND SURF-ZONE MORPHODYNAMICS: A GLOBAL ENVIRONMENTAL MODEL FOR PREDICTING HAZARDS AND CHANGES

L. D. Wright, N. C. Shi, and J. D. Boon, III

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FINAL REPORT

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OFFICE OF NAVAL RESEARCH
COASTAL SCIENCES PROGRAM, Code 422CS
800 North Quincy Street
Arlington, VA 22217

on

Task NR 388-189
Contract N00014-83-K-0198

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The final results of a study aimed at improving the predictability of nearshore, beach, and surf-zone hydrodynamic and morphologic assemblages are summarized in this final report and reported in detail in six accompanying technical reports. Analyses were performed on time series, spanning 6.5 years of daily wave data, daily tide range, and daily beach state; 2 years of daily wave groupiness statistics; and 6.5 years of monthly beach and surf zone profile data with the goal of identifying the

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dominant controls on short-term beach response in order to predict changes. Beach state (the reflective and dissipative extremes and 4 intermediate states) are roughly predictable to a first order in terms of the simple parameter $\Omega = H_b/(w_s T)$ where H_b is breaker height, w_s is sand fall velocity and T is wave period. Each of the six beach states has a different equilibrium range of Ω values and the direction of change depends on the departure from the equilibrium association. ~~In addition,~~ both tide range and groupiness are statistically significant determinants of beach state. Provided that Ω is within the appropriate range to favor beach states at the reflective end of the sequence, spring tides will favor the reflective or low tide terrace states; the transverse bar and rip state is best developed during neap tides. Higher incident wave groupiness favors the more dissipative states and is the major factor favoring the states with pronounced longshore rhythmicity. Empirical eigenvector analyses performed on the profile data permitted separation of different response modes. The lowest order vectors expressing the grosser aspects of the profile features such as beach volume and surf zone gradient displayed maximum variance at periods in excess of 2 years whereas much shorter response times characterized the higher order modes such as bar-trough shapes. The behavior of these higher modes is significantly affected by Ω and tide range. In particular, the more accentuated bar-trough profiles are developed when tide range is minimal. Analyses were performed on a set of field data from a surf zone with highly accentuated bar-trough topography and a numerical model was developed to predict the behavior of standing waves and edge waves over this complex form of natural topography. In contrast to fully dissipative surf zones, the bar-trough surf zone is not at all saturated. Infragravity standing waves which, in dissipative surf zones, dominate the inshore energy, remain energetically secondary and occur at higher frequencies in the bar trough surf zone. Analyses of the field data combined with numerical simulations of leaky mode and edge wave nodal-antinodal positions over observed surf zone profiles, indicate that the frequencies which prevail are favored by the resonant condition of antinodes over the bar and nodes in the trough. Frequencies low enough to have nodes over the bar are suppressed.

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Introduction

The study "Nearshore and Surf-Zone Morphodynamics: A Global Environmental Model for Predicting Hazards and Changes" (NR 388-189) was initiated on 15 February 1983 via a one-year contract from the Office of Naval Research to the Virginia Institute of Marine Science in the amount of \$90,478. The original period of performance was extended at no cost to 31 March, 1984. During this first year the budget was accelerated by an additional \$10,550 to facilitate a subcontract for Dr. Peter Nielsen at the University of Florida. The project was subsequently renewed for an additional year from 1 April, 1984 to 31 March, 1985 with ONR funding of \$96,981 for the additional year. This period of performance was extended to 31 December, 1985 at no additional cost. The project initially evolved from an earlier study (NR 388-157) supported by the Office of Naval Research through the University of Sydney, Australia. The extensive data set obtained during the Australian field study provided the main data base for the Virginia Institute of Marine Science study, described here, which was primarily devoted to analyses and syntheses.

The results of the study are embodied in a series of papers which have been published in refereed literature, are in press in the refereed literature or have recently been submitted for publication. The purpose of this short final report is to provide an executive summary of the main aspects of our results as they relate to the original objectives. The major details of the results are presented in six technical reports (in the form of reprints and manuscripts) which accompany this final report as appendices. Additional details can be found in the other publications which are listed at the end of this report.

Program Objectives

The long-term goal of the project has been to develop improved, accurate predictability of nearshore, surf zone, and beach hydrodynamic and morphologic assemblages, based on elucidation of the universal principles governing nearshore and surf zone morphodynamic behavior. The specific objectives over the period of this contract have been:

1. To characterize and explain the relationships between coastal environmental conditions and time-dependent beach states (i.e. hydrodynamic-morphologic assemblages) and to identify the dynamic parameter which best determines beach state.

2. To quantify, in forms suitable for analysis of long time series of daily morphodynamic behavior, the important characteristics of the nearshore energy regime (e.g. waves and tides).

3. To improve explanation and predictability of short-term changes in the morphodynamic states of beaches and surf zones in terms of the forcing parameters.

4. To improve explanation and predictability of intermediate term variability and changes of two-dimensional beach/surf zone/nearshore profiles and to elucidate the relationships between profiles and beach states.

5. To better explain the morphodynamic connectivities of pronounced bar-trough (linear and rhythmic) surf zone states and to gain better predictability of temporal changes of these systems.

Although Objective 2 might be regarded as a secondary objective, it was one which had to be accomplished before Objectives 3, 4, and 5 could be adequately addressed.

Program Accomplishments

- Objective 1 - Characterization of the different morphodynamic assemblages as expressed by way of the concept of beach state and determination of the primary environmental controls of beach state were completed early in the first year of the study. To a large degree, this represented the final synthesis and report writing from the preceding Australian phase of the study; the first accomplishment of this study therefore overlaps somewhat with the final accomplishments of the antecedent study. The details of these results are presented in Wright and Short (1984) which accompanies this report as Appendix 1 as well as in Wright and Short (1983), Short and Wright (1983) and Short and Wright (1984). In these publications, the morphodynamic and hydrodynamic associations which characterize each of the six beach states shown in Figure 1 are dealt with as are the wave conditions and sediment properties which favor the different states.

Hydrodynamic processes and the relative contributions of different mechanisms to sediment transport and morphologic change differ dramatically as functions of beach state, that is, depending on whether the surf zone and beach are reflective, dissipative or in one of several intermediate states. Depending on beach state, near bottom currents show variations in the relative dominance of motions due to: incident waves, subharmonic oscillations, infragravity oscillations, and mean longshore and rip currents. On reflective beaches, incident waves and subharmonic edge waves are dominant. In highly dissipative surf zones, shoreward decay of incident waves is accompanied by shoreward growth of infragravity energy; in the inner surf zone, currents associated with infragravity standing waves

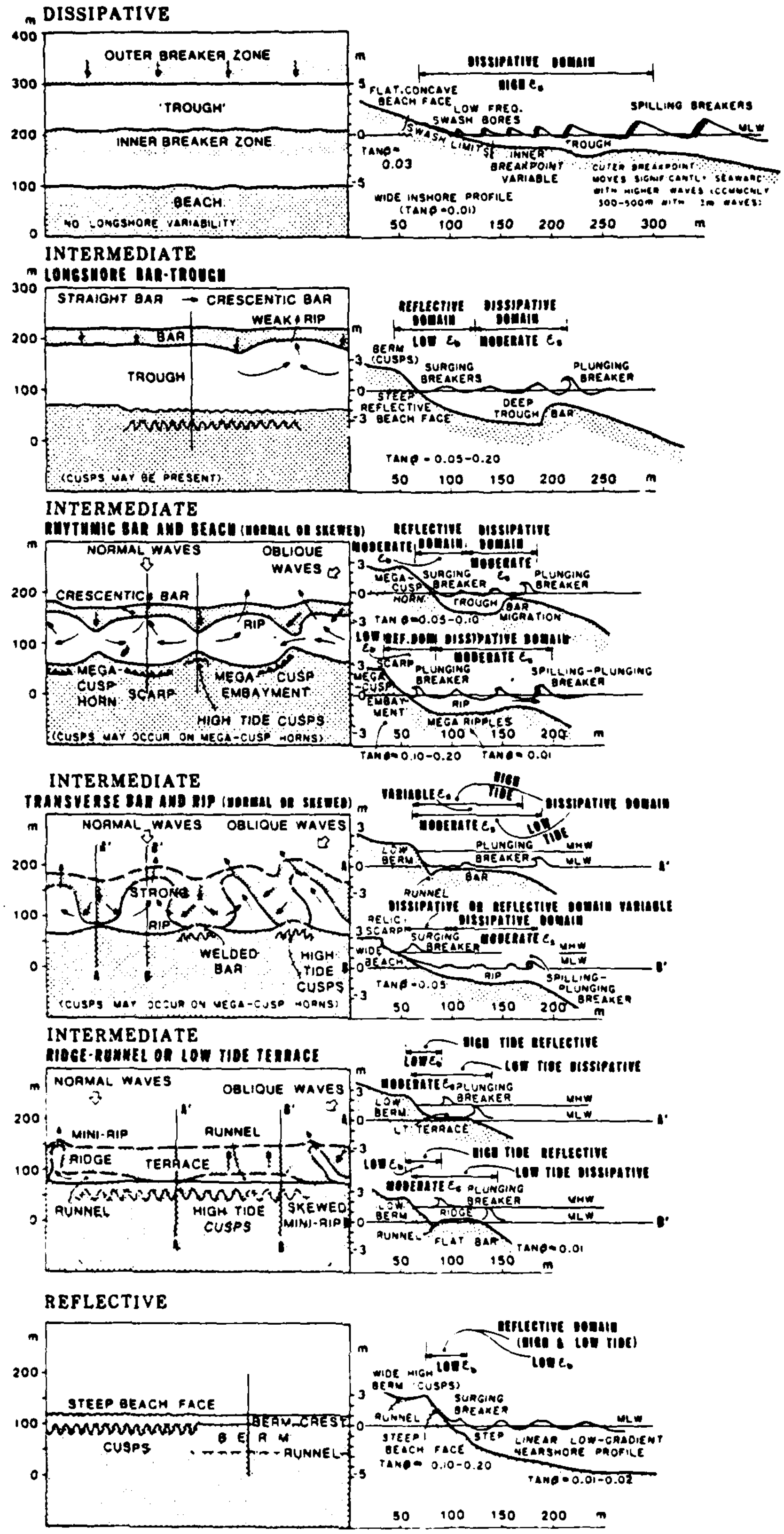

FIGURE 1. Morphodynamic states of surf zones and beaches.

dominate. On intermediate states with pronounced bar-trough (straight or crescentic) topographies, incident wave orbital velocities are generally dominant but significant roles are also played by subharmonic and infragravity standing waves, longshore currents, and rips. The strongest rips and associated feeder currents occur in association with intermediate transverse bar and rip topographies.

Long-term consecutive surveys of different beaches with contrasting local environmental conditions provide the data sets for empirical-statistical assessment of beach mobility, direction of change and response to environmental conditions. Conditions of persistently high wave energy combined with abundant and/or fine grained sediment results in maintaining highly dissipative states which exhibit very low mobility. Relatively low mobility is also associated with persistently low-steepness waves acting on coarse-grained beach sediments. In such cases, the modal beach state is reflective. The greatest degree of mobility is associated with intermediate but highly changeable wave conditions, medium grained sediment and a modest or meager sediment supply. Under such conditions, the beach and surf zone tend to alternate among the intermediate states and to exhibit well-developed bar trough and rhythmic topographies. A good association is found between beach state and the environmental parameter

$$\Omega = H_b/(\bar{w}_s T) \tag{1}$$

where H_b is breaker height, w_s is mean sediment fall velocity and T is wave period. Temporal variability of beach state reflects, in part, the temporal variability and rate of change of Ω, which, in turn depends on deep-water wave climate and nearshore wave modifications.

- Objective 2 - Activities related to the development of effective techniques for expressing the daily variations in Ω, incident wave groupiness, and tide range continued throughout the first 18 months of the study. Although they are not the explicit or sole subjects of any of our publications to date, the developments in connection with this objective underlie the results obtained on Objectives 3 and 4 and are discussed in Wright et al. (1985a; Appendix 2), Wright et al. (1985b; Appendix 3), and Wright et al. (in press; Appendix 4).

For the purposes of the analyses in this study, Ω and a weighted mean value, Ω were computed as in Wright et al. (1985a; Appendix 2). The <u>significant breaker height</u> (after refraction, shoaling and frictional dissipation effects were taken into account) and peak period as obtained from wave rider statistics were used as the H_b and T values in Equation 1. The beach configuration as observed at any given time is more often the product of recently antecedent processes than it is of the processes prevailing at the time of observation. Hence, a weighted mean value, $\bar{\bar{\Omega}}$, taking account of conditions several days prior to observations was computed from

$$\bar{\bar{\Omega}} = \left[\sum_{j=1}^{D} 10^{-j/\phi} \right]^{-1} \sum_{j=1}^{D} (\Omega_j \, 10^{-j/\phi}) \tag{2}$$

where j = 1 on the day just preceding the beach state or profile observations and j = D on D days prior to observation. The parameter ϕ depends on the rate of memory decay. At ϕ days prior to observation, the weighting factor has decreased to 10%. Wright et al. (1985a) found that the highest degree of explanation for the dynamic Narrabeen Beach was achieved with ϕ = 5 days and D = 30 days so those values were used subsequently.

We reviewed the existing techniques for quantifying the degree of wave groupiness. One such method was based on a smoothed instantaneous wave energy history, which is merely a squared and then low-passed filtered [illegible] wave time series. However, due to the non-linear computations [illegible] the calculation, the groupiness factor thus defined does not [illegible] upper and lower limits. This makes the intercomparison of [illegible] factors among different time series difficult to interpret. [illegible] improved groupiness factor GF in terms of a wave envelope or groupiness time series g_t,

$$GF = \frac{\sqrt{2}\ \sigma_g}{\bar{g}_t} \qquad (3)$$

(σ_g = standard deviation of $\bar{g}_t$, g_t = mean of g_t). The groupiness series g_t was obtained by low pass filtering the absolute value of the wind wave band sea surface time-series and scaling the result with a factor of $\pi/4$. This simple method of complex demodulation produces a visually excellent envelope function that closely follows 1/2 the wave amplitude. The groupiness factor GF given here thus represents a measure of wave amplitude variability and has a well-defined upper limit of 1 for perfectly grouped waves and a lower limit of 0 for waves with constant wave amplitude. Figure 2 illustrates the g_t and groupiness factor correspondence to different wave time-series.

In order to relate wave groupiness to daily beach state and monthly beach profile data as was done in Wright et al. (in press; Appendix 4), it was necessary to obtain daily time series of unprocessed offshore wave data from the Sydney Region (near Narrabeen Beach from which the data come) encompassing times during which beach observations were made. We obtained

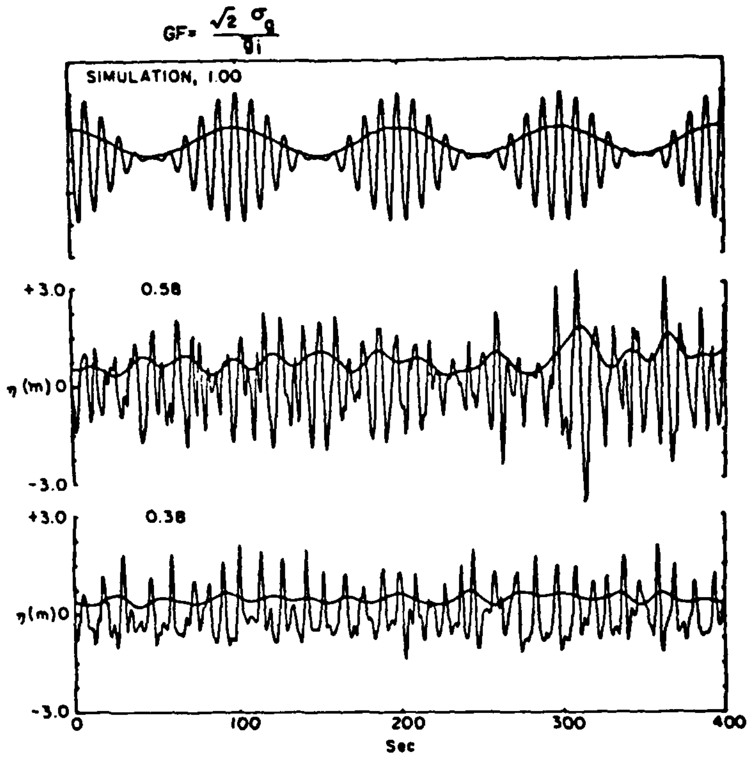

FIGURE 2. The relationship between the grouping factor , GF, and sea-surface (η) time series of a hypothetic "perfectly" grouped wave train with GF = 1 (upper curve) and two natural wave time series with GF = 0.58 and 0.38. The large displacement curves are the actual wave time series; the smoother low amplitude curves represent the time series of g_t.

from the N.S.W. Maritime Services Board a data set covering 613 days of 1977 and 1978 (the period over which our data set has the fewest interruptions). For each day covered by the data there are on average 3 time series per day giving us a total over 1,800 time series. Each time series is about 18 minutes long; the sampling interval (Δt) was 0.5 sec. We analysed each series for groupiness and found daily averages to obtain a 613 day groupiness time series. As in the calculation of $\overline{\overline{\Omega}}$, $\overline{\overline{GF}}$ was weighted using Equation 2 to account for antecedent conditions.

Long period variations in the tide include periodic components having semimonthly, monthly, semiannual and annual periods. The tidal constituents used to represent these temporal variations in water level are well known and may be extracted from records of the observed tide using simple filtering methods and harmonic analysis. The linear combination of these constituents yields the familiar seasonal tide curve which, on a given day, suggests little more than a linear trend in water level rise or fall and shows the local sea level stand in relation to yearly mean sea level. What is not shown in a seasonal tide curve is the contribution made by tidal range to sea level variance at time scales longer than those of the major semidiurnal and diurnal tidal components (i.e. M2, S2, N2, K1 and O1). Usually we see this variation in daily (hourly) tide curves as a beat frequency or a modulation on what we may regard as the carrier wave of the tidal signal, the M2 tide, as it interacts with the other constituents of lesser amplitude but similar frequency.

We used 37 tidal constituents to compute tidal range (TR) and mean (daily) sea level time series embracing the same period as our daily beach

state and Ω data. We employed the same method of complex demodulation used in computing the groupiness time series except that longer filter cutoffs are used in the case of the tides and amplitudes are a factor of 2 larger than for the groupiness envelope function. Multiplying all of the new values by π, the series is made to contain the same mean range value as the original series. Using a low pass filter with a cutoff period of approximately 72 hours (we use a least squares digital filter with a filter width of 24 hours), the final series emerges that shows the tidal range as a function of time. Figure 3 shows a one-year time series of time varying tide range and associated mean sea level as computed by this method from the tidal constituents for Sydney. In order to allow for the potential importance of antecedent conditions, weighted mean values of daily tide range, $\overline{\overline{TR}}$, were estimated using the same technique as was used in estimating $\overline{\overline{\Omega}}$ (Eq. 2). These values are also shown in Figure 3 (by the crosses).

- Objective 3 - As is implied by the title of our project, one of the main thrusts of our effort has been to gain an ability to predict the short term changes in the six beach states shown in Figure 1 in terms of readily determined environmental parameters such as Ω, groupiness and tide range. The results of the initial analyses, which treated beach state as a function of Ω and $\overline{\overline{\Omega}}$ only, are reported by Wright et al. (1985a & b; Appendices 2 and 3).

A time series of 6.5 years of daily observations of beach states and wave characteristics from southeastern Australia was analyzed with the aim of determining the degree to which time-varying beach state can be explained and predicted. The six commonly occurring beach states (dissipative,

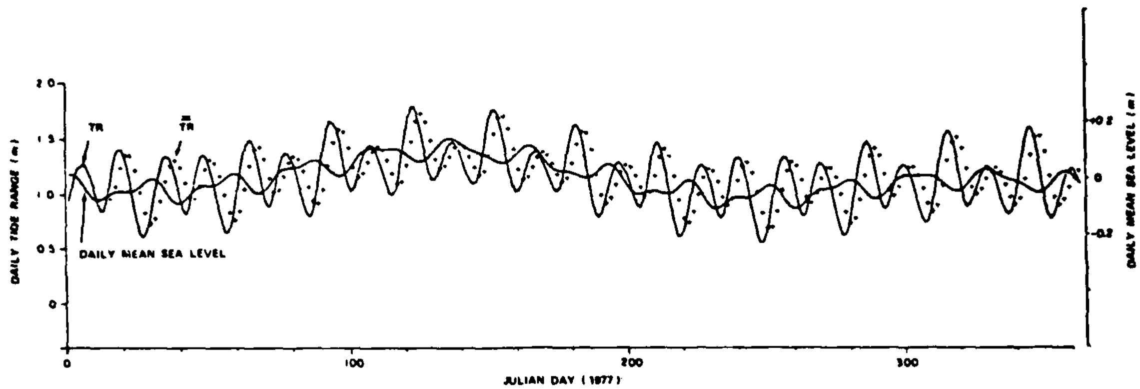

FIGURE 3. Predicted daily variations in tide range, TR, weighted tide range $\overline{TR}$ and the corresponding daily mean sea level (the smoother, lower amplitude curve) for 1977.

longshore bar trough, rhythmic bar and beach, transverse bar and rip, low-tide terrace, and reflective), discussed earlier, were related, by means of discrete discriminant analyses, to the parameter Ω using a total of 1545 cases. Two Ω values were used in the analyses: the immediate value occurring on the day the particular state was observed and a weighted mean value expressing recently antecedent conditions. The immediate value made a negligible contribution to explaining day-to-day beach state observations; however, the antecedent conditions showed a strong relationship and provide a successful means of prediction.

By examining cases where the time derivatives of both state and Ω were near zero, it was possible to define the equilibrium conditions associated with each state. Directions of change (erosional or accretionary) are predicted in terms of departures of Ω from the equilibrium value, Ω_e, appropriate to the beach state prevailing at the time change begins. Figure 4 illustrates diagrammatically the relationships between the equilibrium region and rates of changes. The arrows showing rates and directions of change are based on averages estimated from several values within Ω intervals of 0.5. The blunt ends (origins) of the arrows are located so as to correspond to the initial beach state from which the change is occurring. The solid line through the middle of the graph indicates the mean Ω_e values corresponding to each beach state and the shaded region embraces one standard deviation of Ω_e either side of the mean. Within this region the beach may be expected to remain relatively stable.

The empirical analyses of short-term beach and surf zone morphodynamic response to changing breaker conditions by Wright et al. (1985a & b; Appendices 2 and 3) are extended by Wright et al. (in press; Appendix 4) to

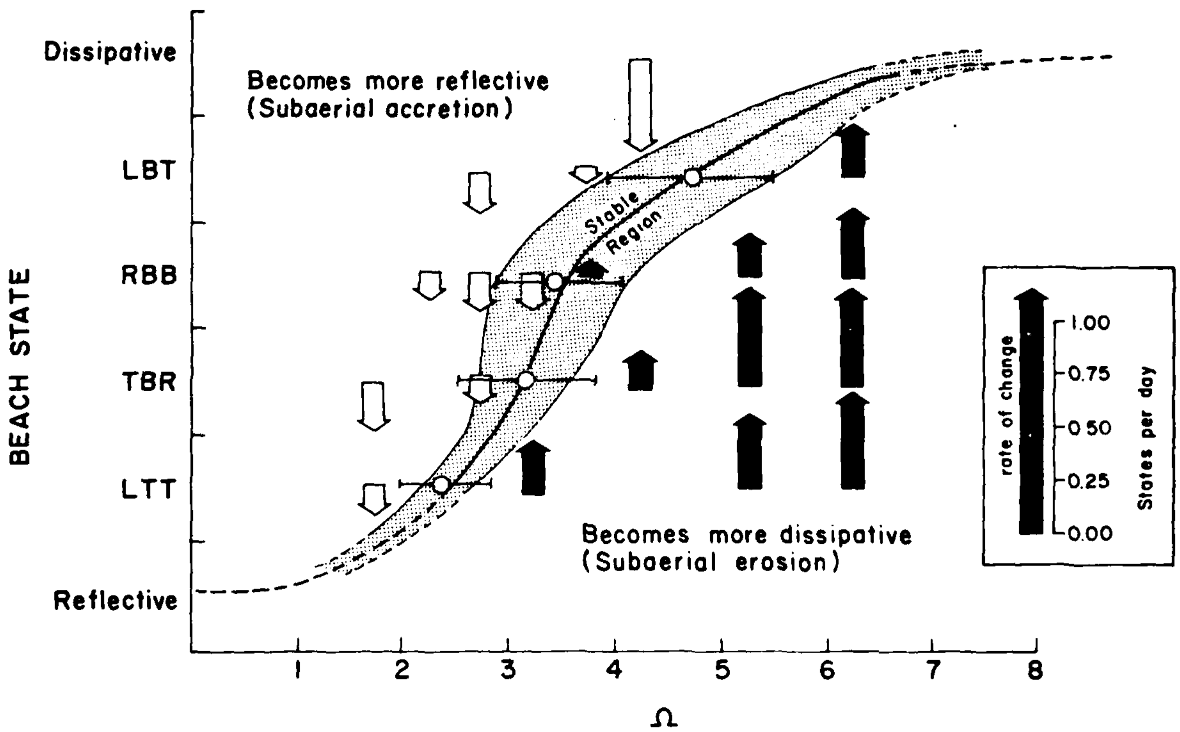

FIGURE 4. Beach state equilibria and directions and rates of change. The central curve indicates the mean equilibrium associations between state and Ω.

examine the additional roles played by daily tide range and incident wave groupiness. Complex demodulation of original tide and wave time series from the moderate energy Narrabeen Beach, Australia, resulted in new time series of daily tide range and a daily grouping factor which expresses the relative amplitude of the alternation between groups of high and low waves. Using these new time series together with time series of daily beach state and of the parameter Ω, statistical analyses were performed aimed at determining the contributions made by each factor in explaining time-varying beach state. Figure 5 shows an example of the time series used in these analyses.

Both tide range and groupiness are significant determinants of beach state. The six beach states are reflective, low-tide terrace, transverse bar and rip, rhythmic bar and beach, longshore bar trough, and dissipative (Wright and Short, 1984). Provided that Ω is within the appropriate range to favor beach states at the reflective end of the sequence, spring tides will tend to favor either the low-tide terrace or reflective states over the transverse bar and rip state. The transverse bar and rip state is best developed during neap tides. Higher tide ranges are also associated with more subdued bar-trough topography; the more accentuated bar-trough profiles are developed when tide range is minimal. Overall, higher relative incident wave groupiness favors the more dissipative states. Incident wave groupiness is the dominant factor determining whether the low-tide terrace state or transverse bar and rip state prevails, provided Ω is such as to permit one or the other of these states. Groupiness is also important in discriminating between the transverse bar and rip and rhythmic bar and beach states. Figure 6 indicates how the effects of $\overline{\overline{GF}}$ and $\overline{\overline{TR}}$, when superimposed on Ω, affect beach state.

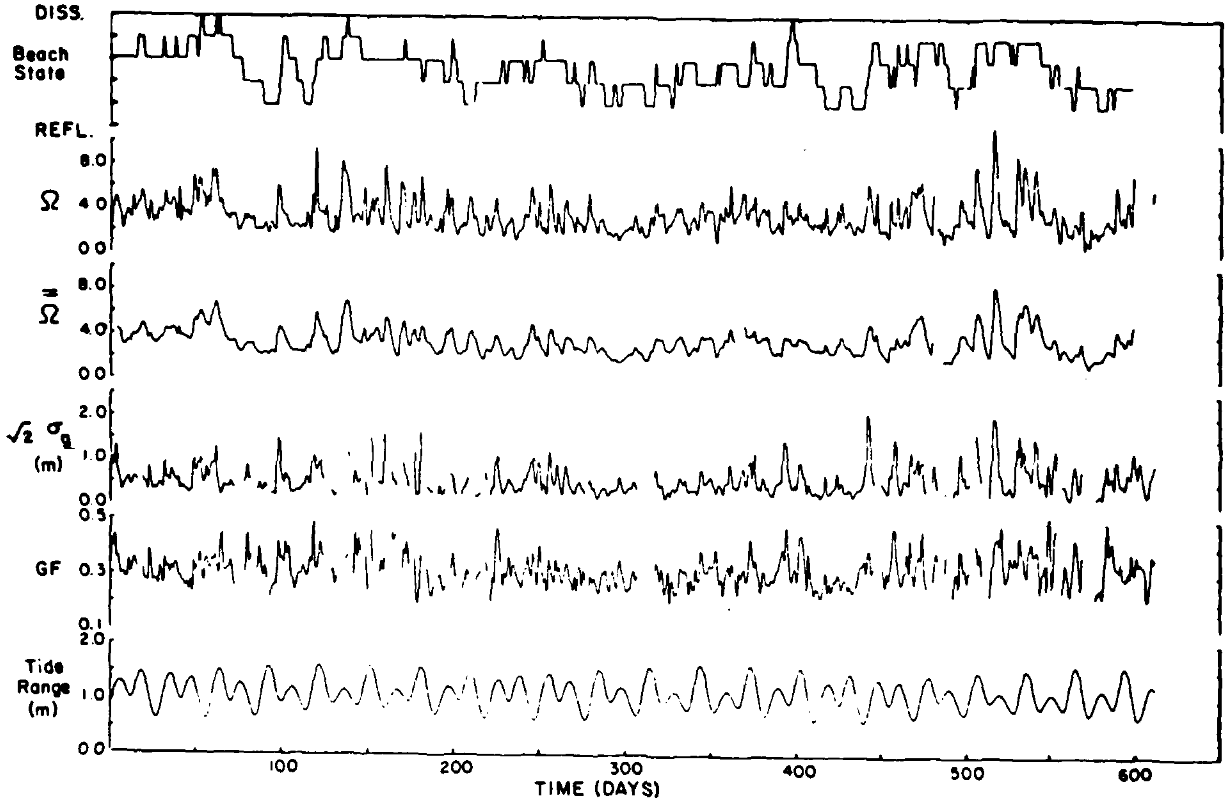

FIGURE 5. Time series of daily beach state and daily Ω, $\bar{\bar{\Omega}}$, $\sqrt{2}\ \sigma_g$, GF, and tide range, TR for Narrabeen Beach indicating the type of data used for the statistical analyses. (The actual period covered by the series shown is 1 January 1977 to September 1978.)

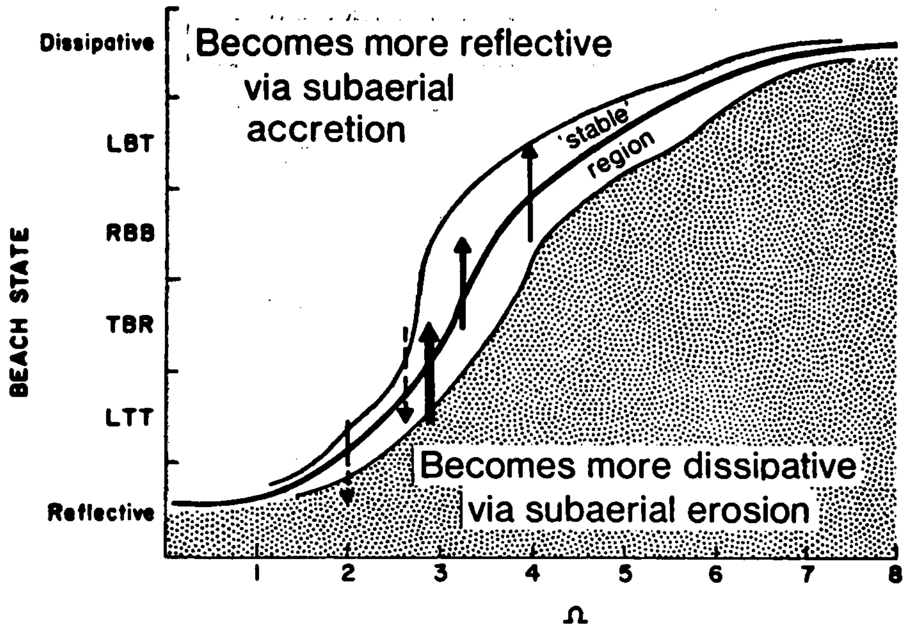

FIGURE 6. Directions of beach state change as determined by antecedent beach state, Ω, TR, and GF. The effects of TR and GF are mainly exerted when the beach is in the "stable" region with respect to prevailing beach state and Ω combinations. The dashed arrows indicate the effects of increased tide range on beach state. The solid arrows indicate the effects of increased groupiness on beach state; in this case relative variations in the importance or strength of the effect are shown by varying arrow thicknesses with the thickest arrow designating the strongest effect.

- Objective 4 - The same 6.5 year data set from Narrabeen Beach, as used in the beach state analyses, includes biweekly to monthly beach and surf zone profiles. The data set from the monthly levelling transects of beach and surf zone profiles was subjected to considerable further reduction prior to attempting to establish causal relationships. Specifically, different, approximately independent, modes of profile behavior were separated by means of principal components analyses. In these analyses empirical eigenvectors were calculated at the University of Virginia from the correlation matrix by Dr. S. May whom we employed as a temporary research associate during the first year of the study. Results of the profile analyses are reported by Wright et al. (1985b; and in press; Appendices 3 and 4).

Empirical eigenvector analyses provided an objective, quantitative characterization of changing profile shapes. Basically, the analysis transforms a set of intercorrelated variables into a new coordinate system in which the axes are linear combinations of the original variables and are mutually orthogonal. Two types of analyses were conducted: (1) in the first ("fixed datum") the eigenvectors express profile variability referenced to a fixed datum; (2) in the second ("floating datum") the profile variability is referenced to the instantaneous position of the shoreline and is independent of absolute degree of accretion or erosion. The latter analyses best express profile shape and can be related to beach state. The lower order eigenvectors (E_1, E_2) express the grosser aspects of the profile such as beach volume, width and gradient. More complex profile features such as bar-trough configurations, asymmetries, and steps are expressed by progressive addition of higher vectors (E_3, E_4, E_5).

In terms of the fixed datum modes, most of the variance in the profile of Narrabeen Beach is accounted for by eigenvector 1 which expresses beach width and sediment volume; eigenvector 1 is, in essence, a sand storage function. A positive weighting on eigenvector 1 indicates an accreted profile (relative to the mean) whereas a negative weighting indicates an eroded profile. The amplitudes of profile changes associated with eigenvectors 2-4 are small relative to those associated with eigenvector 1. The maximum and only consequential variance in eigenvectors 1 and 2 is seen to occur at periods of two or more years. Temporal variations in eigenvector 1 directly parallel variations in subaerial beach volume; the weightings on this vector are coherent and in phase between all profiles along Narrabeen Beach indicating that a shore-normal rather than a longshore redistribution of sediment is responsible for the changes (Wright et al., 1985b; Appendix 3).

The floating datum modes of profile variation are independent of absolute sand storage volume and beach width and are therefore better able to describe the behavior of profile shape. Figure 7 illustrates the meaning of the signs of weightings (+ or -) on the 5 dominant modes and Table 1 indicates the relationships between the vector weightings and beach state. The first eigenvector expresses the overall flattening (+ weighting) and steepening (- weighting) of the surf zone and beach and thus characterizes the relative degree of dissipativeness or reflectivity of the system. This mode of variation is most effective in discriminating between the two extreme beach states. Pronounced bar-trough topography yields positive weightings on both eigenvectors 2 and 3; the absence of bars is expressed by negative weightings on both of these vectors. Accordingly, the strongly

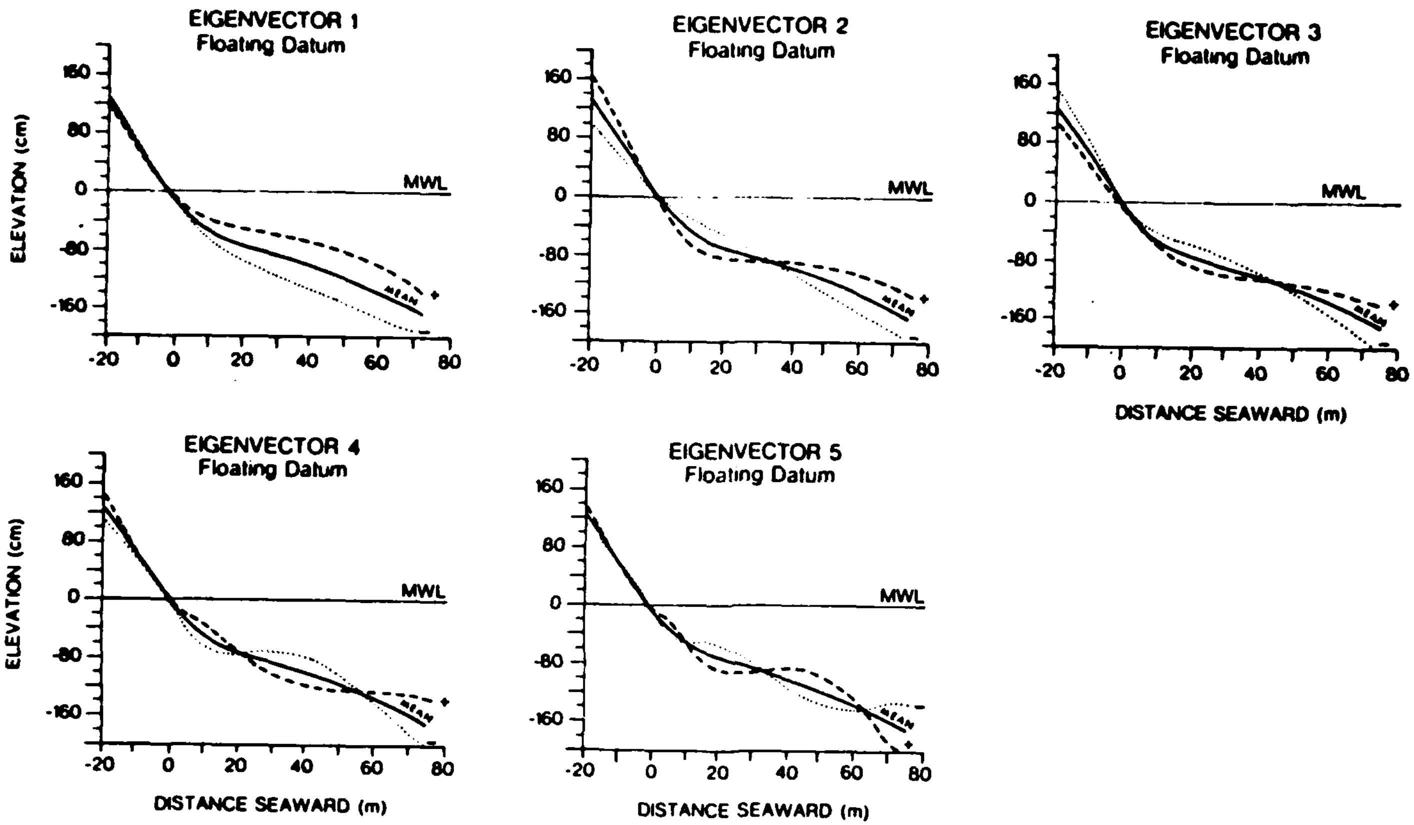

FIGURE 7. The five floating datum modes of beach and surf zone profile variation. The mean profile is indicated by the solid curve. Positive and negative weightings on each vector are indicated respectively by the dashed and dotted curves. The actual profile as it appears at any given time expresses the addition of the different modes of profile shape.

TABLE 1. Relationships Between Beach State and the Signs of Weightings on the Five Floating Datum Eigenvectors.

Floating Datum Eigenvector No.	Beach State					
	Refl.	LTT	TBR	RBB	LBT	Diss.
E1	-- *	-	~0	~0	-	++ *
E2	-	-	+	+	+	-
E3	-	-	~0	+	+	+
E4	+	~0	~0	-	+	~0
E5	+	+	+	-	~0	-

*Extreme negative and extreme positive weightings are indicated by -- and ++ respectively.

barred states are distinguished from the other states on the basis of the weightings on eigenvectors 2 and 3 in combination. Adjacent and somewhat similar intermediate states are discriminated between in terms of the higher vectors. For example, eigenvector 4 distinguishes between the longshore bar trough state (+ weighting) and the rhythmic bar and beach state (- weighting) while eigenvector 5 distinguishes the rhythmic bar and beach state from the transverse bar and rip state (Wright et al., 1986; in press; Appendices 3 and 4).

Analyses of the frequency-response characteristics of the different modes of profile behavior were reported by Wright et al. (1985b; Appendix 3). The power spectrum of the weightings on eigenvector 1 shows the dominant peak to be centered at periods between 24 and 42 months. This suggests that the largest amplitude variations in overall profile gradient or "dissipativeness" are related to the same long-period processes that produce the major variations in gross sand storage. The existence of a secondary but significant peak at about 2.3 months indicates that profile gradient is also responsive to higher frequency forcings. The dominant variations in eigenvectors 2 through 5 occur at periods of 2 to 6 months. This corresponds to the period band of the largest amplitude fluctuations in beach state as discussed earlier. However, it must be noted that eigenvectors 2-5 all exhibit appreciable variance at periods of 2 years or more. We infered from this that even the higher-order aspects of profile shape --and hence beach state-- are significantly overprinted by slow oscillations in inshore sediment storage.

The results of examining the roles of $\bar{\bar{\Omega}}$ and weighted daily tide range, $\overline{\overline{TR}}$ in forcing changes in the different profile modes are reported by Wright

et al. (in press; Appendix 4). No significant relationships were found for eigenvectors 1 or 5. In the case of eigenvector 1 which primarily involves flattening or steepening of the surf zone, the dominant variations are long-term (> 1 year) and are closely tied to the processes controlling slow exchanges of sediment between the shoreface and the surf zone. As indicated by Table 1, the sign of the weighting on vector 5 reverses depending on whether the beach state is TBR or RBB; the distinction between these two beach states appears to be significantly influenced by $\overline{\overline{GF}}$. The grouping factor, $\overline{\overline{GF}}$ was not included in the analyses of profile behavior because the $\overline{\overline{GF}}$ data cover a period which embraces only 20 surveys.

Significant associations between $\overline{\overline{\Omega}}$ and $\overline{\overline{TR}}$ and profile behavior were found for eigenvectors 2, 3 and 4. Probably the most important point is that vectors 2 and 3, the two "bar-trough" functions are each dominated by different forcings. Eigenvector 2 tends *to* be *positive* (*pronounced* bar-trough) when tide range is lower and negative (subdued bar-trough topography or barless) when tide range is higher. Tide range ($\overline{\overline{TR}}$) is more than twice as important as $\overline{\overline{\Omega}}$ in contributing to this behavior. In contrast, eigenvector 3 seems to depend almost entirely upon $\overline{\overline{\Omega}}$: larger (but not extreme) values of $\overline{\overline{\Omega}}$ favor positive weightings on vector 3 and hence better developed bar-trough topography (the mean $\overline{\overline{\Omega}}$ values related to -, 0, and + weightings on vector 3 are respectively 2.8, 3.3 and 3.5). Tide range also has a relatively unimportant effect on vector 4; the role of $\overline{\overline{\Omega}}$ is significant but not highly significant. The effect of $\overline{\overline{\Omega}}$ on vector 4 parallels that described for vector 3: larger values are associated with positive weightings.

- Objective 5 - The most enigmatic of the beach states are those which exibit highly accentuated bar and trough topography (the longshore-bar-trough state and the rhythmic bar and beach state). We addressed several hitherto unresolved questions concerning the morphodynamics of bar-trough surf zones: (a) What are the topography-induced effects on the infragravity standing waves of these systems which cause the infragravity standing oscillations to be higher in frequency and lower in energy than on unbarred beaches or in surf zones with more subtle bars? (b) What factors (wave conditions, degree of groupiness, tide range) select in favor of bar-trough surf zones? (c) How are these systems maintained? (d) What causes the transition from the linear longshore-bar-trough state to the rhythmic-bar-and-beach state?

Questions (a) and (c) are dealt with in detail by Wright et al. (1986; Appendix 5) and Shi and Wright (in press; Appendix 6). Questions (b) and (d) are considered by Wright et al. (in press; Appendix 4).

Characteristic features of the morphology of bar-trough surf zones are shown in Figure 8; they include a shallow bar with a steep shoreward face, a deep trough, and a steep beach face. This morphology, which is favored by moderate breaker heights and small tidal ranges, strongly controls the coupled suite of hydrodynamic processes. In contrast to fully dissipative surf zones, the bar-trough surf zone is not at all saturated and oscillations at incident wave frequency remain dominant from the break point to the subaerial beach. The degree of incident wave groupiness does not change appreciably across the surf zone. Infragravity standing waves which, in dissipative surf zones, dominate the inshore energy, remain energetically secondary and occur at higher frequencies in the bar trough surf zone.

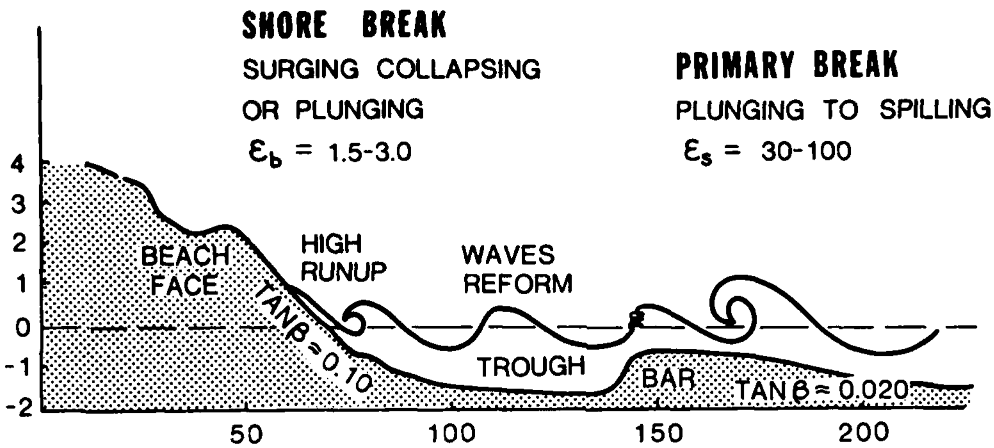

FIGURE 8. Major characteristics of a bar-trough surf zone.

Analyses of the field data combined with numerical simulations of leaky mode and edge wave nodal-antinodal positions over observed surf-zone profiles, indicate that the frequencies which prevail are favored by the resonant condition of antinodes over the bar and nodes in the trough. Standing waves which would have nodes over the bar are suppressed. Sediment resuspension in the surf zone appears to be largely attributable to the incident waves which are the main source of bed shear stress. In addition, the extra near-bottom eddy viscosity provided by the reformed, non-breaking waves traversing the trough significantly affects the vertical velocity profile of the longshore current. Whereas the bar is highly mobile in terms of onshore-offshore migration rates, the beach face and inner regions of the trough are remarkably stable over time.

The hypothesis that pronounced bar-trough surf zone topography favors resonance of standing waves with antinodes over the bar is examined in greater detail by Shi and Wright (in press; Appendix 6). To address this problem, a numerical algorithm was developed to solve, numerically, equations for leaky mode standing waves and edge wave modes over natural, complex topography. Predictions from the model were compared with field data from an Australian bar-trough beach experiment. Figure 9 shows the model predictions of the amplitude function for a constant slope beach as compared with a pronounced bar trough profile. The presence of the bar is seen to alter, appreciably, the cross-shore amplitude distribution and the positions of nodes and antinodes. In addition, standing waves which have antinodes over the bar are seen to experience an increase in amplitude over the bar. Both the numerical model results and field data suggest a selective trapping of wave energy at specific resonant frequencies in the

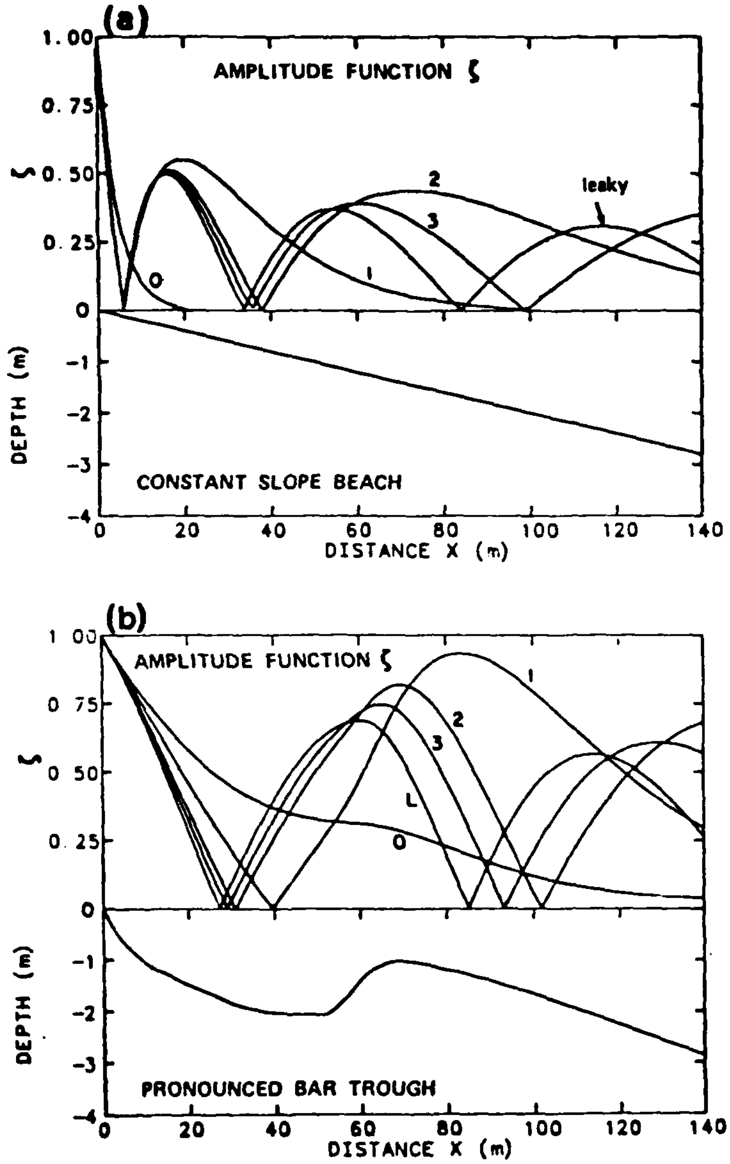

FIGURE 9. Amplitude function $\zeta(x)$ for a constant slope beach and a pronounce bar trough beach (wave period = 30 s). Shown in the figure are the leaky (L) mode and up to mode 3 edge wave solutions.

subharmonic and the high frequency infragravity bands and a possible suppression of lower frequencies. The resonant frequencies predicted by the numerical model remain fairly constant throughout the tidal cycle due to the small tidal range typically associated with a bar-trough beach. Cross-shore bar migration changes the resonant frequencies. Numerical simulations show that an onshore bar migration will be accompanied by a reduction in the period of the resonant wave and a decrease in the longshore wave length of the possible edge wave mode.

Limitations of the Results

Overall, we feel that this project has resulted in the elucidation of many of the controls on beach and surf zone morphodynamic behavior and brought us considerably closer to an ability to predict changes. We are, however, obliged to offer a caveat. We had hoped, originally, to obtain a set of empirical equations for predicting the time-varying state and profile configuration of a beach and surf zone in terms of $\overline{\overline{\Omega}}$, $\overline{\overline{TR}}$, and $\overline{\overline{CF}}$. In fact, the necessary coefficients for "predictions" are embodied in our statistical results; however, we feel that a predictive "recipe" based solely on our data would be unreliable and not universal. The associations we found are, in many cases, highly significant, but they are not direct and specific enough to permit quantitative predictions to be made worldwide within prescribed error limits. There are several reasons for the limitations to our success: (1) The paramount shortcoming of our approach has been our neglect of the shoreface and inner shelf. Subsequent investigators must extend their surveys well beyond the surf zone at least to the depth of "closure" as is presently done by personnel at the Corps of Engineers Field

Research Facility at Duck, North Carolina. (2) Monthly resurveying is far too infrequent to permit causal associations to be identified between rapidly changing waves and beach conditions. Surveys at daily or shorter intervals including surveys during high-energy events, are needed and are now obtainable by means of surf zone sleds such as that used by Sallenger and his co-workers. It seems unlikely that significant new insights into nearshore morphodynamic processes will be gained from further "conventional" infrequent (order monthly) surveys of the beach and surf zone. (3) The true roles of temporal variations in tide range are probably poorly elucidated by the Narrabeen data set since neither the mean tide range nor the neap-to-spring range are very large at that site. What is needed is a comparable time series from a relatively energetic beach in a mesotidal environment where the neap-to-spring variation is large.

Publications Obtained in Connection With This Study

a. Major articles focused specifically on the objectives of this study (these articles accompany this report as Appendices 1-6).

Wright, L. D. and Short, A. D., 1984. Morphodynamic variability of surf zones and beaches: A synthesis, Mar. Geol. 56, pp. 93-118 (Appendix 1).

Wright, L. D., Short, A. D. and Green, M. O., 1985. Short-term changes in the morphologic states of beaches and surf zones: An empirical predictive model, Mar. Geol. 62, pp. 339-364 (Appendix 2).

Wright, L. D., May, S. K., Short, A. D. and Green, M. O., 1985. Beach and surf zone equilibria and response times, Proc. Int. Conf. Coastal Engineering, 19th, Houston, Sept., 1984, pp. 2150-2164 (Appendix 3).

Wright, L. D., Short, A. D., Boon, J. D., Hayden, B., Kimball, S. and List, J. H., in press. Morphodynamic responses of an energetic beach to temporal variations in wave steepness, tide range, and incident wave groupiness, submitted to Mar. Geol. (Appendix 4).

Wright, L. D., Nielsen, P., Shi, N. C. and List, J. H., 1986. Morphodynamics of a bar-trough surf zone, Mar. Geol. 70, in press (Appendix 5).

Shi, N. C. and Wright, L. D., in press. Standing waves on a pronounced bar-trough beach, Jour. Geophys. Res. (Appendix 6).

b. Articles resulting in whole or in part from the support of this study but focused on subjects peripheral to but relevant to the primary objectives.

Short, A. D., 1983. Sediments and structures in beach-nearshore environments, Southeast Australia, in McLachlan, A. and Erasmus, T. (eds.), Sandy Beaches as Ecosystems, Dr. W. Junk Publishers, The Hague, pp. 145-155.

Short, A. D. and Wright, L. D., 1983. Physical variability of sandy beaches, in McLachlan, A. and Erasmus, T. (eds.), Sandy Beaches as Ecosystems, Dr. W. Junk Publishers, The Hague, pp. 133-144.

Wright, L. D. and Short, A. D., 1983. Morphodynamics of beaches and surf zones in Australia, in Komar, P. D. (ed.), Handbook of Coastal Processes and Erosion, CRC Press, pp. 35-64.

Nielsen, P., 1984. Field measurements of time-averaged suspended sediment concentrations under waves, Coastal Engineering 8, pp. 51-72.

Nielsen, P., 1985. On the structure of oscillatory boundary layers, Coastal Engineering 9, pp. 261-276.

Short, A. D. and Wright, L. D., 1984. Morphodynamics of high energy beaches --an Australian perspective in Thom, B. G. (ed.), Coastal Geomorphology in Australia, Academic Press, pp. 43-68.

Shi, N. C., Larsen, L. H. and Downing, J. P., 1985. Predicting suspended sediment concentration on continental shelves, Mar. Geol. 62, pp. 255-275.

Shi, N. C. and Larsen, L. H., 1986. Topographic eddies in a tidal estuary, Proc. Symposium on Circulation Patterns in Estuaries (Gloucester Point, 1985; in press).

c. Conference presentations with published abstracts.

Shi, N. C. and List, J. H., 1984, Variability of storm wave groupiness in the nearshore zone, AGU Fall Meeting, San Francisco, Dec. 1984 (abstract in EOS, vol. 65, p. 959).

Wright, L. D., Shi, N. C. and List, J. H., 1984. Infragravity oscillations in the presence of accentuated bar-trough surf zone topography, AGU Fall Meeting, San Francisco, Dec. 1984 (abstract in EOS, vol. 65, pp. 958-959.

Wright, L. D., May, S. K., Short, A. D. and Green, M. O. Prediction of beach and surf zone morphodynamics: Equilibria, rates of change, and frequency response, 19th International Conf. on Coastal Engineering, Houston, Sept., 1984 (abstract published in Abstract Volume).

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